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Process for manufacturing a semiconductor assembly, such as a silicon rectifier

Applicant:
Westinghouse Electric Corporation,
East Pittsburgh, Pa. (USA)
Representatives: Dr. Eng. P. Ohrt, Patent Attorney
Erlangen, Werner-von-Siemens-Str. 50

Required priority:
USA on May 9, 1957

Charles P. Gazzara, Fayetteville, N.Y., and David L. Moore, Jeannette, Pa. (USA), were named as inventors

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The invention relates to a process for manufacturing a semiconductor assembly, such as a silicon rectifier, whose semiconductor body that is provided with electrodes is connected to a mounting plate that has a nearly identical thermal expansion coefficient as that of the semiconductor body and which is itself attached to another support and/or a housing.

When manufacturing semiconductor assemblies with silicon pn-junctions, the silicon material must be in the form of an extremely thin plate that is approximately 125 to 375 μ thick. Silicon plates are very brittle and sensitive, so that they break or splinter easily if they are exposed to any mechanical stress. Such a break may not only be caused during the manufacture and assembly of rectifiers that contain such silicon plates, but also during use based on the deviating thermal expansions that exist between the silicon plate and the mounting plate to which it is connected, since the rectifier device that it contains heats up during operation.

Another problem that develops during the manufacture of satisfactory rectifiers made of silicon semiconductor materials is the need to quickly and effectively dissipate the heat they develop during operation. Excess temperatures of over approximately 220°C may adversely affect operation of the rectifier if it is subject to considerable electrical load while at such increased temperatures.

The silicon plate must therefore be mounted on a metal with excellent thermal conductivity.

It is also necessary that the material used as a mounting plate be doused thoroughly and evenly with soft soldering material in order to assure excellent thermal electrical contact between the mounting plate and an additional support and/or housing to which it is attached.

After silicon diodes are assembled, it is customary to treat the assembly with chemical corrosives. The chemical corrosives, which are generally produced from strong acids, such as nitric acid and hydrofluoric acid, are used to clean the silicon diode around the surface of the pn-junction of the silicon plate and the counter electrode or the upper contact link, in order to improve the electrical characteristics of the diode. It is desirable that the mounting plate consist of a material that will not be dissolved by the chemical corrosive or will not

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affect the perfect operation of the silicon diode if small quantities of the material are loosened by the corrosive.

Following the manufacture of the silicon diode assembly, the assembly is hermetically sealed in order to protect the silicon and other parts of the assembly against atmospheric conditions. When sealing the diode, it is customary to first mount the mounting plate on a second support and/or housing which may be shaped like a metal cup containing a recess..

This is generally performed by means of soldering.. A solder with a low melting point is applied in order to connect the mounting plate of the diode assembly to the additional support and/or housing. It has been observed that the temperature required for this procedure should not exceed approximately 400°C. Temperatures above approximately 400°C may adversely affect the characteristics of the diode circuit. Because of this temperature limitation, soft solder must be used that has a melting point under 400°C, and in fact, preferably under 300° C. It has been determined that soft solder materials do not produce a good mechanical connection that has good thermal conductivity with such metals as tungsten, tantalum, and the basic alloys thereof. Satisfactory operation of the complete configuration may be affected as a result.

The problems that arise from these considerations during the manufacture of a semiconductor assembly of the mentioned type may be solved perfectly and technically advantageously in that in the process according to the invention at least one surface of the mounting plate facing the additional support or housing is specially coated with metal before the mounting plate is connected to the semiconductor body which assures that the surface coated with this metal will be thoroughly and evenly doused and will be resistant against chemical corrosives, and after the mounting plate and the semiconductor body are joined together the configuration consisting of the mounting plate and the semiconductor body is subjected to a treatment with a chemical corrosive and subsequently soldered to the additional support and/or housing using soft solder.

A process for manufacturing semiconductor assemblies based on a semiconductor body made of germanium or silicon already exists as prior art, according to which the semiconductor body is mounted on a mounting plate made of a metal, such as molybdenum or tungsten, that has a heat expansion coefficient similar to that of the semiconductor body, whereby the semiconductor body is soldered to the mounting plate and the mounting plate is soldered to a cooling plate made of copper, aluminum, nickel or iron. For this purpose the already mentioned mounting plate made of molybdenum or tungsten is gold coated, for example, by an electrolytic method, on the side facing the semiconductor body. Tin is used as solder between the mounting plate and the semiconductor body in this prior art process, whereby an additive of donors or acceptors could be added. Silver is used as solder between the mounting plate and the additional support and/or cooling plate. Because of this hard soldering that is done with the use of silver, the semiconductor system cannot be completed in this conventional process to include the mounting plate, since the cited soft solder connection using tin between the mounting plate and the semiconductor body, as well as its simultaneous doping, naturally cannot be performed until after the hard soldering between the mounting plate and the cooling body has taken place. Therefore, in this conventional process no soft solder connection between the mounting plate and an additional support and/or housing is present, and thus it is impossible to fully complete the semiconductor assembly along with the etching before making the soft solder connection to the additional support by means of its mounting.

Prior art also exists in which the mounting plate of a semiconductor element is provided with a silver coating on both surfaces after cleaning. However, it is well known that this coating is not resistant to corrosives, so that an undesired contamination of the corrosive solution can occur during the etching treatment of the semiconductor element, which again could undesirably contaminate the pn-junction of the semiconductor element that has to be etched for cleaning.

Finally, in prior art for semiconductor assemblies, the semiconductor element is attached to a mounting plate by soldering and after this mounting plate is mechanically connected to a bell-shaped housing on the bottom of a cup-shaped mounting that has a connecting bolt projecting from its surface that lies vis-à-vis from the inner surface, it is mounted such that soldering is done between the edge of the previously mentioned cup-shaped object and the outer, suitably metal-coated surface of the ceramic, bell-shaped housing.
In this case, therefore, no soldering between the large surfaces of the mounting plate and the additional support and/or housing is done, which, if done, would assure a significantly improved electrical and thermal junction between the mounting plate and the additional reinforcement.

According to the process set forth in the invention, the mounting plate may be provided with a coating of a metal from a group that consists of gold, platinum, and rhodium.

The coating may be applied to the mounting plate by galvanization, spraying, or rolling on. The coating may be of any desired thickness. The thickness of the coating may, for example, be in the range of approximately 25μ as the upper limit and 0.25μ as the lower limit.

When using gold or platinum, it may be advisable to apply a coating that is approximately 5μ thick, and when using rhodium to apply a coating that is 0.5 μ thick. The mounting plate for the semiconductor body may be made of tantalum, tungsten, or basic alloys of these materials that have a thermal expansion coefficient that is near to that of the silicon.

Tantalum and tungsten have a linear thermal expansion coefficient of essentially the same value as silicon, viz., approximately 4.2×10^{-6}/°C. Alloys of tantalum and tungsten, for example, an alloy that consists of 5% tungsten and 95% tantalum also, have almost the same expansion coefficient as silicon. Tantalum and tungsten may be alloyed with lower amounts of other metals without significantly modifying their thermal expansion coefficients. Tungsten may therefore be alloyed with 5% to 25 percent by weight of a platinum metal, such as osmium or platinum, chrome, nickel, cobalt, silicon or silver. A thermal expansion coefficient of approximately between 3.8×10^{-6}/°C and 6.5×10^{-6}/°C is satisfactory for use with a silicon plate.

Tantalum, tungsten and their alloys which have a thermal expansion coefficient that approaches that of silicon have an excellent thermal conductivity, so that the heat from the silicon with which it is in contact is dissipated quickly.

Prior to applying the metal coating, the mounting plate is cleaned by scraping, etched, and washed to remove all surface contaminants , even if scraping by sandblasting alone would also suffice under certain conditions.

To explain the invention in greater detail using embodiments of the invention, reference will now be made to the figures shown in the drawings, during the explanation of which additional, advantageously applicable individual characteristics will come to light.

Figure 1 is a cross-section of a semiconductor device which is assembled according to the invention and

Figure 2 is a cross-section of a modified form of the embodiment.

For reasons of simplicity, tungsten will specifically be the metal of reference . However, it should be understood that tantalum or any other alloy of tantalum or tungsten that has a thermal expansion coefficient corresponding to that of silicon, may also be used in its stead.

In figure 1 of the drawing an example of a semiconductor diode is shown which is suitable to be screwed into any device board or other equipment. The diode **10** contains a mounting plate **12**, which contains a body **14** that is manufactured of metal which is selected from a group of metals consisting of tantalum, tungsten and their alloys and has a thermal expansion coefficient that approaches that of silicon and has a thin coating of a layer **16** of a metal that is selected from the group of metals that includes gold, platinum, and rhodium. A layer of a basic silver solder **18** is applied to the upper surface of the mounting plate **12** to provide for the stability of a fused metallurgical junction between the mounting plate and a silicon plate **20** which is located on the mounting plate **12**. A layer **22** of an aluminum metal is fused or alloyed on to the upper surface of the silicon plate **20** which is selected from the group of metals that includes aluminum and aluminum alloys. A nail-shaped counter electrode **21** made of tantalum, the horizontal shank of which has a level front surface **26** is fused to the upper surface of the aluminum coating **22**. The vertical shank **28** of the tantalum counter electrode **24** is relatively flexible and is provided for supplying power to the diode. The mounting plate **12** is attached to the additional support and/or housing **30** which has a threaded projection **32**.

A recess **34** is located in the upper surface of the screw **30**, within which the mounting plate **12** is mounted. which is attached to the additional support and/or housing and/or the threaded base plate **30** by a layer **36** of soft solder.

The thin layer **18** that is made of silver solder and connects the silicon plate **20** to the mounting plate by fusion may consist of a silver alloy with a high or low melting point. Suitable basic silver solders consist of silver and either one element of group IV of the periodic table or one doping contaminant of the n-type or both. The alloys are a combination of at least 5% silver and a remainder that must not contain more than 90 percent by weight of tin, 20 percent by weight of germanium, nor 95 percent by weight of lead, and does contain a small ratio of antimony or another n-doping contaminant. Especially good results have been obtained with the following binary alloys (dual material alloys), in which all parts are dimensioned according to their weight. Alloys of this type are 35 to 10% silver and from 65 to 90% tin; 95 to 84% silver and from 5 to 16% silicon; 75 to 50% silver and from 25 to 50% lead and 95 to 70% silver as well as from 5 to 30% germanium.

Ternary alloys of silver, tin and silicon; silver, lead and silicon; silver, germanium and silicon are especially advantageous. For example, ternary alloys (triple material alloys) may consist of 50 to 80% silver and of 5 to 16% silicon and the remainder is tin, lead, or germanium. The silver alloy may contain small amounts of other elements or contaminants provided, however, that no significant amount of group III elements is present. The basic silver solder may contain up to 10 parts by weight of antimony. Excellent results were therefore achieved by using solder that contain:

1. 98% of silver
   1% of lead
   1% of antimony

2. 80% of silver
   16% of lead
   4% of antimony

3. 85% of silver
   5% of silicon
   8% of lead
   2% of antimony.

When these silver alloys are applied to the silicon plate, some silicon on the plate dissolves in the alloy and as a result binary or ternary alloys, which contained no silicon when applied, contain a small, but significant, amount of silicon after the alloying process. By this method, an alloy which consists of 84% silver, 1% antimony, 10% tin and 5% germanium, which is applied to the silicon plate therefore contains from 5 to 16 percent by weight of silicon after the alloying process, depending on the length of the time and the temperatures to which the solder alloy and the silicon were subjected.

Excellent results have been obtained with alloys that contain from 1 to 4 percent by weight of antimony and where the remainder consists of from 98 to 92 percent by weight of silver. Thin layers of these ternary silver alloys were applied to the silicon plate and after the configuration was heated up to the soldering temperature, the silver alloy melted and dissolved a part of the silicon, and a part of the silicon diffused into the alloy so that the alloy junction coating contains from 5 to 16 percent by weight of silicon, approximately 1 to 4 percent by weight each of lead and antimony and the remainder consists of silver. The lead-antimony-silver alloy is ductile and may be easily rolled out into thin films that are 25 to 50μ thick. The thin films are then cut or stamped into small pieces of approximately the same surface area as the silicon plates and are applied to these plates.

The basic silver alloys may be produced in powder or grain form and a thin coating thereof applied to the end surface of the contact either in dry form or in the form of a paste in a volatile solvent, such as perhaps ethyl alcohol. The thin layer 22 of an aluminum metal, which has been applied to the upper surface of the silicon plate 20, may consist of a film or a foil of aluminum or a basic aluminum alloy, preferably of a basic aluminum alloy with an element from group III or IV (or both) of the periodic table. The aluminum share must consist of a material which when it is fused onto the silicon plate 20 dissolves some of the underlying silicon and when it is

cooled, again excretes silicon which has a p-conductivity on the upper parts of the plate **20**.

The coating **22** may consist of pure aluminum with only negligible amounts of contaminants, such as those of magnesium, zinc or the like, or of an alloy whose the main component is aluminum and whereby silicon, gallium, indium and germanium constitute the remaining parts any one, two, or all of which may be present These alloys should not melt below 300°C. Thus, foils may be used, whereby all parts are measured according to percent by weight, such as 95% aluminum and 5% silicon; 88.4% aluminum and 11.6% silicon; 90% aluminum and 10% germanium; 47% aluminum and 53% germanium; 88% aluminum and 12% indium; 96% aluminum and 4% indium; 50% aluminum, 20% silicon, 20% indium and 10% germanium; 90% aluminum, 5% silicon and 5% indium; 85% aluminum, 5% silicon, 5% indium, and 5% germanium; 88% aluminum, 5% silicon, 2% indium, 3% germanium and 2% indium.

It is crucial that the aluminum coating **22** be considerably smaller than the surface area of the silicon plate **20** and that it be centered on the plate **20** in such a manner that it is at a clear distance from the corners and edges of the semiconductor plate. It is not necessary that the aluminum coating **22** be a foil or a separate layer. It has been established that it is possible to vapor-deposit aluminum or basic aluminum alloys onto the silicon plate in a vacuum. Selected central parts of the upper surface of the silicon plate may be vapor-deposited ed with aluminum or basic aluminum alloys by masking (covering) the edges of the plates, or the upper contact itself may be vapor-deposited with the aluminum metal.

During the manufacture of the diode shown in figure 1, the assembly that consists of the base plate contact **12**, the silver solder **18**, the silicon plate **20**, the aluminum element **22**, and the upper tantalum contact element **24** is vacuum heated at a temperature of approximately 800 to 1000°C. while the parts are held together under light pressure. The silver solder **18** is melted during a brief period of time and will have combined with the base plate **12** of the silicon plate **20**. The aluminum coating **22** will be melted in the same manner and it will have entered into a junction with the tantalum contact **24** during the cooling process and have effected a metallurgical junction with the upper surface of the silicon plate **20**. The aluminum will dissolve the bordering silicon on the upper boundary of the silicon plate during the heating process and the dissolved silicon will be separated with p-conductivity during the cooling process, whereby in this way the bordering upper surface parts are converted into silicon with p-conductivity which produces a pn-junction. When the alloyed configuration is cooled to room temperature, it is etched. Following the etching, the alloyed configuration is mounted in *a* recess **34** of an additional support and/or housing and/or a threaded base plate **30** with a solder **36** that has a low melting point which, for example, one that melts below 300°C and is then applied to produce a fusion joint between the diode circuit and the element **30**. The temperature during this

final operation should not exceed approximately 400°C. The diode **10** shown in figure 1 of the drawing may be encapsulated or mounted in a hermetically sealed metal housing to protect the silicon and other parts of the configuration against environmental conditions.

An excellent mechanical connection is formed between the mounting plate **12** and the additional support and/or housing or the threaded base plate **30**. The thin layer **16** made of gold, platinum or rhodium produces a surface on the mounting plate **12** which is thoroughly and evenly doused with soft solder.

A modified form of a semiconductor assembly **50** is illustrated in figure 2 of the drawing. The diode circuit **50** consists of an additional support and/or housing or a threaded base plate **52** which has a projection **54** that is provided with threads. A recess **56** is provided on the upper front surface of the threaded base plate **52** within which a mounting plate **60** is located. This mounting plate **60** consists of a body **62** made of tantalum, tungsten, or basic alloys thereof which have a thermal expansion coefficient of essentially the same value as silicon and it is completely enclosed in a thin layer **64** of metal, which is selected from the group that includes gold, platinum, or rhodium. The mounting plate **60** is securely connected to the threaded base plate and/or the additional support or housing **52** by a solder **65**that has a low melting point.

A silicon plate **66** is mounted on the upper surface **60** which has previously been cut to a suitable size and shape. The silicon plate has been lapped and etched in order to produce a plate which has the desired semiconductor characteristics. The plate may be doped with an n- doping contaminant to give it the desired n-conductivity. A thin layer of the basic silver solder **68** produces a fused connection between the silicon plate **66** and the base plate contact element **60**. A rod-shaped, aluminum counter electrode **70** which has been selected from the group of aluminum and aluminum alloys is welded together with the silicon diode. The counter electrode **70** may have the same composition as the layer **22** shown in figure 1.

The semiconductor assembly **50** is produced in a manner similar to that used in the manufacture of the semiconductor assembly **10** shown in figure 1. The aluminum counter electrode **70** is welded into its place on the plate **66** by passing an electric current through the configuration. Leads carrying electric current may be attached mechanically or by hard soldering to the upper end of the counter electrode **70**.

The semiconductor diode shown in figure 2 is subjected to a thorough etching process before the mounting plate **60** itself is attached to the threaded base plate element and/or the additional support or housing **52**.

The etching treatment cleans the junction between the aluminum counter electrode **70** and the silicon plate **66**, in order to preclude ineffective operation of the resulting diode circuit.

A mounting plate which is made of tungsten is affected adversely by the strong chemical corrosives that are customarily used. It is therefore desirable to enclose the tungsten body completely in a gold, platinum, or rhodium coating that is not permeable. If only the surface of the tungsten body that experiences contact with the additional support and/or housing is coated, it is important that no corrosives contact the exposed surface of the tungsten body. If the coating is applied to the entire tungsten body, the corrosive may be applied by any conventional method without causing any undesirable results.

Tantalum is not adversely affected by corrosives that are normally used. A mounting plate that is made of tantalum therefore only has to be coated on the particular surface that is connected to the additional support and/or housing or the threaded base plate by fusion.

Suitable corrosives consist of a mixture of equal volumetric parts of nitric acid and hydrofluoric acid. The hydrofluoric acid may consist of 48 to 50% HF (hydrofluoric acid) and the nitric acid may have a concentration of 25%. Other suitable corrosives for silicon are well known within professional circles.

PATENT CLAIMS:

1. Process for manufacturing a semiconductor assembly, such as a silicon rectifier, whose semiconductor body that is provided with electrodes is connected to a mounting plate that has a nearly identical thermal expansion coefficient as that of the semiconductor material, and which is itself attached to an additional support and/or housing, **characterized by the fact that** (1) prior to being connected to the semiconductor body, the mounting plate is – at least on the surface facing toward the additional support or housing – especially coated with a metal that assures a thorough and even dousing of the surface coated with this metal and is resistant to chemical corrosives and (2) after the mounting plate has been connected to the semiconductor body, the configuration consisting of a mounting plate and a semiconductor body is subjected to a treatment with chemical corrosives and is subsequently soldered to the additional support and/or housing using soft solder.
2. Process according to claim 1, characterized by the fact that the mounting plate is coated with a metal from a group of metals that includes gold, platinum and rhodium
3. Process according to claim 1 or 2, characterized by the fact that the mounting plate is coated galvanic ally by spraying or plating it with metal.
4. Process according to one of the claims 1 through 3, characterized by the fact that the mounting plate is provided with an approximately 5μ thick coating of gold or platinum.
5. Process according to one of the claims 1 through 3, characterized by the fact that the mounting plate is provided with an approximately 0.5 μ thick coating of rhodium.
6. Process according to one of the claims 1 through 5, characterized by the fact that the semiconductor body is connected to a mounting plate which is made of one or more metals from the group that includes tantalum, tungsten and basic alloys thereof.
7. Process according to one of the claims 1 through 6, characterized by the fact that the mounting plate is provided with a special coating on all sides.
8. Process according to claim 1, characterized by the fact that the semiconductor body is soldered together with the mounting plate using a silver solder which dissolves the bordering semiconductor material during its fusion process.
9. Process according to claim 8, characterized by the fact that a multiple material alloy is used as silver solder...
10. Process according to claim 9, characterized by the fact that a silver solder is used that consists of 0.5 to 8 percent by weight of antimony, at least 72 percent by weight of silver and the remainder of at least one element of the group of metals that includes germanium, silicon, lead and tin.
11. Process according to claim 1, characterized by the fact that a counter electrode connection contact made of tantalum is connected to the semiconductor body via a coating of aluminum or an aluminum base alloy by an alloying process in such a manner that the pn-junction is produced in the semiconductor body simultaneously with the alloying process.
12. Process according to claim 1, characterized by the fact that a counter electrode connection contact made of aluminum or of an aluminum base alloy is directly connected to the semiconductor body itself in an alloying process such that simultaneously with the alloying process the pn-junction is produced in the semiconductor body.
13. Process according to claim 12, characterized by the fact that the counter electrode contact body is welded electrically to the semiconductor body.
14. Process according to claim 1, characterized by the fact that a cup-shaped object with an assembly bolt projecting from its outer surface, is used as additional support and/or housing and serves directly as a template for inserting the solder and the mounting plate, and that the mounting plate is soldered to the cup-shaped object via its surface that is located vis-à-vis from the bottom surface of the cup-shaped object.
15. Process according to claim 11 or 13, characterized by the fact that the surface of the counter electrode contact body that is to be connected to the semiconductor body is metal-coated with aluminum that serves as the alloying substance.

Literature applied as reference:
German Patent No. 858 925;
British Patent No. 772 583;
US Patent No. 2 763 822;
Swiss Patent No. 316 01

Attached hereto is one sheet of drawings

DRAWINGS PAGE 1 DATE OF ISSUE: AUGUST 4, 1960

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Figure 1

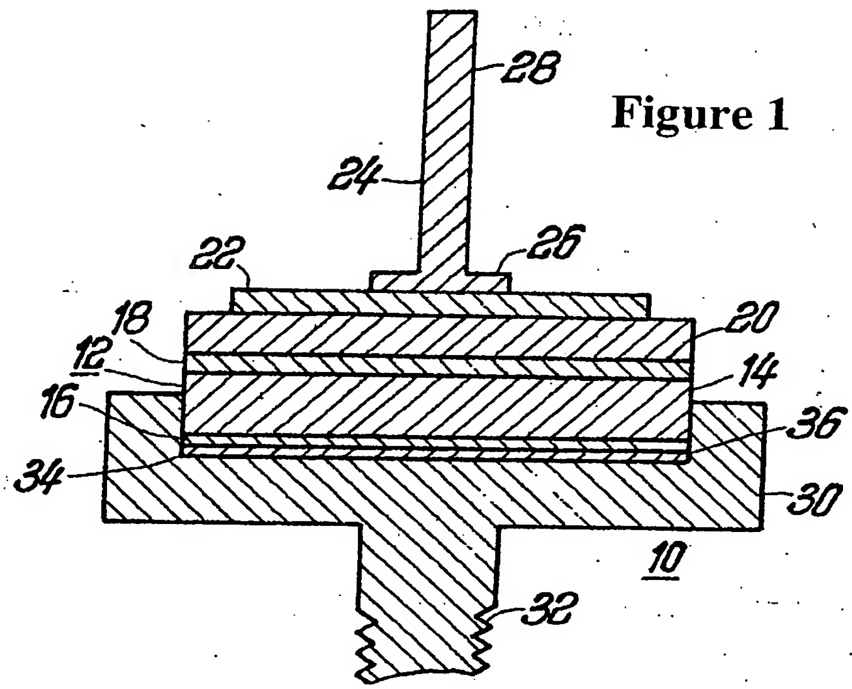

Figure 2